Final OBES Report
The Influence of Carbon on the Electrical Properties of Crustal Rocks
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Objectives: The intent of this work is to comprehend the electrical conduction mechanisms in carbon-bearing rocks and in mantle minerals for the purpose of relating electrical conductivity measured in the field to the nature and origin of carbon in crustal rocks and to temperature in the mantle.

Project Description: Electrical conductivity depends strongly on temperature and on the presence of other phases such carbon, fluids, or ore minerals at the lower temperatures of the crust and basins. One research approach is to measure conductivity of mantle minerals as functions of temperature, orientation, oxygen fugacity fO_2, and iron content. These data supply the best models for "electrogeotherms" yet available. Another approach is to document textures of carbon in crustal rocks from basins and metamorphic zones and relate them to rock conductivity. In this case the nature of the carbon is determined by time-of-flight mass spectroscopy (ToF-SIMS) and its distribution determined by electron microbeam techniques in the same samples used for conductivity measurement.

Results: This project began with work to apply the technique of ToFSIMS to the study of carbon compounds on microfracture surfaces of crystalline rocks. Among the samples studied were amphibolites from 4.6 and 9.1 km depth in the KTB borehole. These rocks exhibit an extensive, interconnected networks of carbonaceous films on cracks and grain boundaries as determined by electron probe. In the sample from 9.1 km depth, ToF-SIMS showed that the carbon is almost completely elemental. In contrast, the carbonaceous matter in the samples from 4.6 km depth is a mixture of elemental carbon and simple hydrocarbons such as alkanes, and possibly C-O-H compounds. The microcracks in the 4.6 km sample also contain a retrograde micro-assemblage consisting of ferri-oxy-hydroxide, calcite, and possibly clay minerals, suggesting that the carbonaceous matter and retrograde minerals formed together at relatively high crustal levels and at a time much later than peak metamorphism. Because the carbon films likely influence the electrical conductivity of the rocks in situ, we hypothesized that production of electrically insulating hydrocarbons during retrograde metamorphism of grain boundary and microcrack carbon tends to increase the resistivity of the rocks and that this chemical destruction of the interconnectivity of electrical pathways contributes to the observed diminished electrical conductivity of the shallow crust relative to the deep crust.

A pilot project was conducted using ToF-SIMS to help develop and test a new protocol involving coating the sample with gold and then removing the coat from only the analytical region by laser while the sample is in the high vacuum of the instrument. The test demonstrated the utility of this technique for study of carbon on microfracture surfaces. Coating followed by laser ablation subtly changed mass distribution in the low-mass region of the mass spectra, but enhanced the intensity of the high mass region (m/e = 100-1000) without significant change in mass distribution. The tests were conducted on a carbon-bearing amphibolite metasediment from the 3.8 Ga old Isua supracrustal belt, Greenland. Graphitic carbon with $\delta^{13}C$ of about –19 per mil had been found in some of the Isua rocks and interpreted as biogenic. The ToF-SIMS work demonstrates the presence of a hydrocarbon fraction, suggesting that some of the carbon could have been introduced after metamorphism.

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An interdisciplinary workshop was convened that included forty petrologists and geophysicists from Europe and North America. The workshop was held at the American Museum of Natural History, New York, on April 18 and 19, 2001. Although general consensus was reached on the importance of carbon in producing upper crustal electrical conductivity anomalies, the situation for the lower crust was much less clear. One problem is simply that some lower crustal features are unseeable because uplift, by whatever mechanism, modifies microstructure and generally modifies geochemistry, even subtly, in fresh rocks. Although geophysical methods lack spatial and temporal resolution and laboratory deformation experiments are poor matches for in-situ crustal conditions, geophysical researchers were more confident of carbon as an explanation of conductivity anomalies than were most petrologists present. For instance, there was no consensus on what constitutes viable mechanisms for mobilizing and precipitating carbon at pressures and temperatures of the deep crust. Further, there is the problem that thermodynamic equilibrium may not prevail on microcracks because of unknown kinetic and shear effects and because the carbon may not be purely graphitic. However, veins of graphite described from New Hampshire demonstrate the mobility of carbon, presumably transported as CO_2, with or without graphitized wall rocks in sillimanite-grade schists, and gneisses. The location of the graphite veins appears to be tectonically controlled, with deposition near the top and possibly much deeper in the lower crust. Issues that need further attention include: measurement of electrical properties of hydrous minerals that may be stable in the crust; how the interconnectivity of carbon can be dynamically maintained at lower crustal to upper-mantle conditions where equilibrium conditions would tend to produce isolated graphite crystals; and experimental observations of mechanisms for destruction of interconnected carbon films during laboratory simulation of near-surface crustal conditions.

TOPICAL KEYWORDS:
Properties of Earth Materials
Resource Definition and Utilization
Hydrocarbon Formation

SCIENTIFIC KEYWORDS:
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Carbon

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